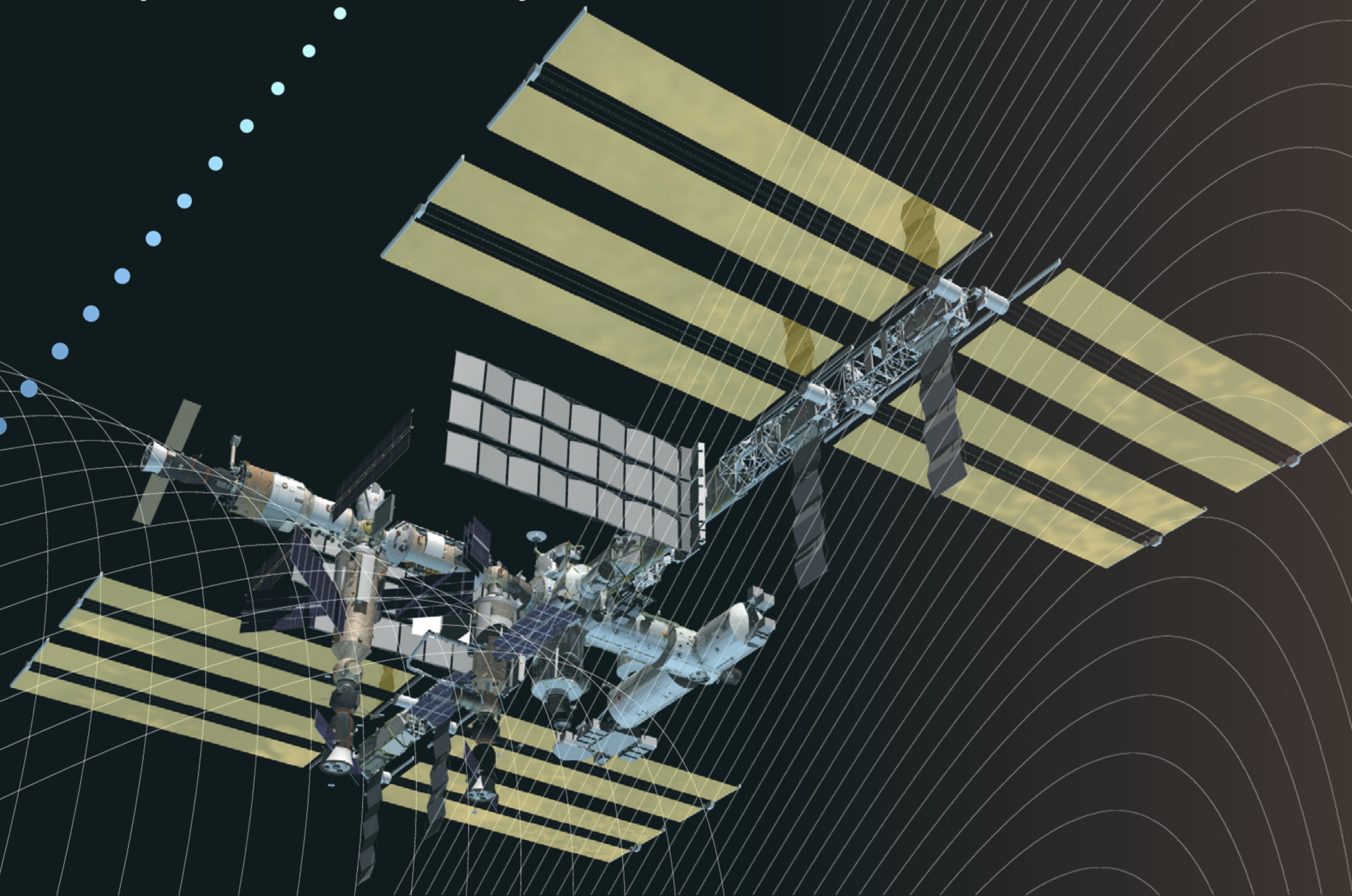
Opportunities for Science on the ISS

A Unique Laboratory Environment

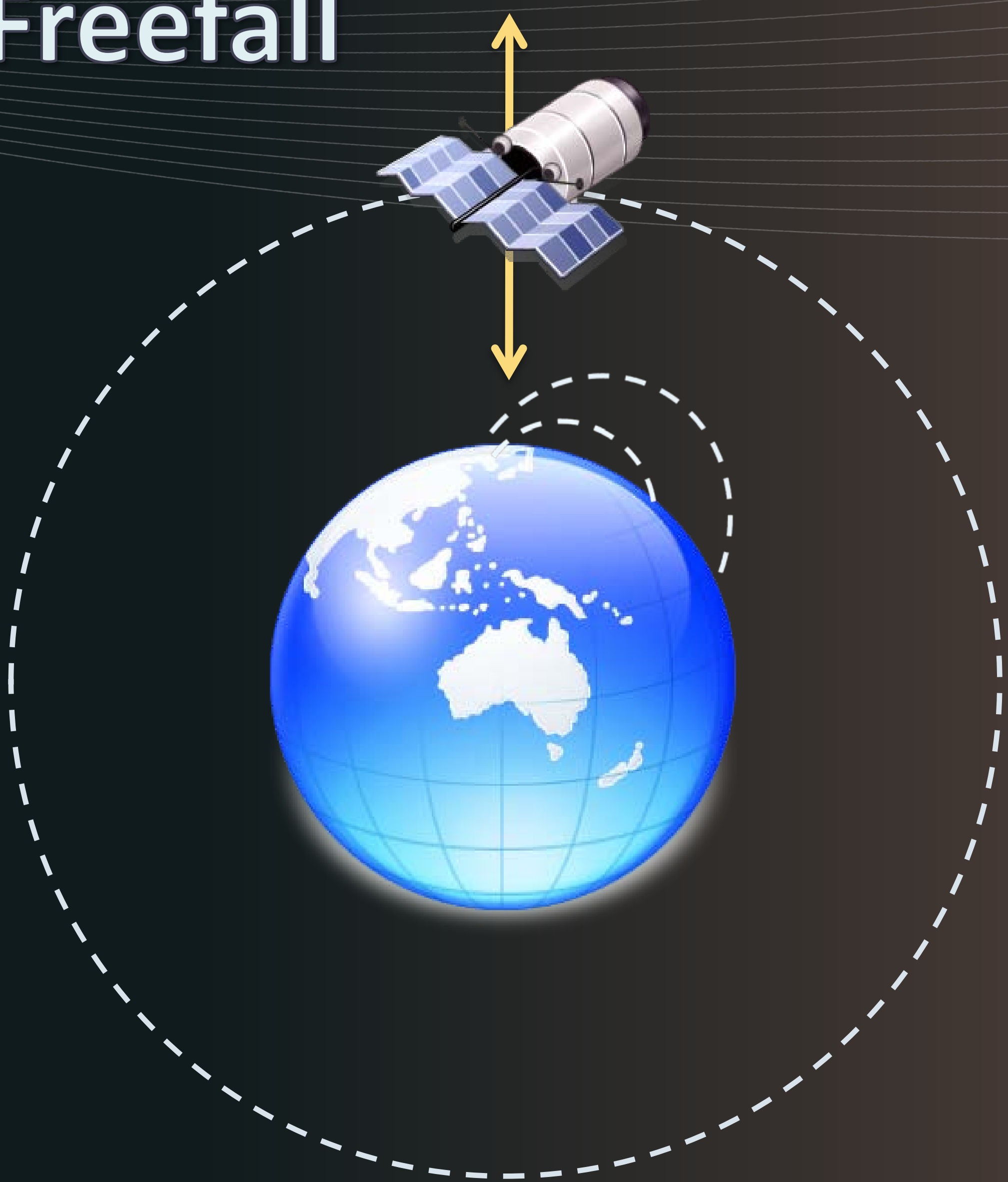


Introduction

- **The Earth's Surface**
  - Weight felt because ground pushes against us
  - Physics, chemistry, and biology dominated by the effects of gravity
- **Low Earth Orbit**
  - Force of gravity is actually 89% of sea level normal
  - We don't feel it in orbit because we're in a state of perpetual freefall

Freefall

- In orbit, we fly fast and high enough to fall and not hit the Earth
- The centripetal force from circular motion is equal and opposite to the force of gravity



The International Space Station

- **A Unique Platform for Science**
  - Crew tended
  - Suitable for long-term studies
- **Critical Capabilities**
  - Microgravity
  - Exposure to the thermosphere
  - Observations at high altitude and velocity

Microgravity is Different

- **Critical phenomena affected by or dominant in microgravity**
  - Surface wetting & interfacial tension
  - Multiphase flow & heat transfer
  - Multiphase system dynamics
  - Solidification
  - Fire phenomena & combustion

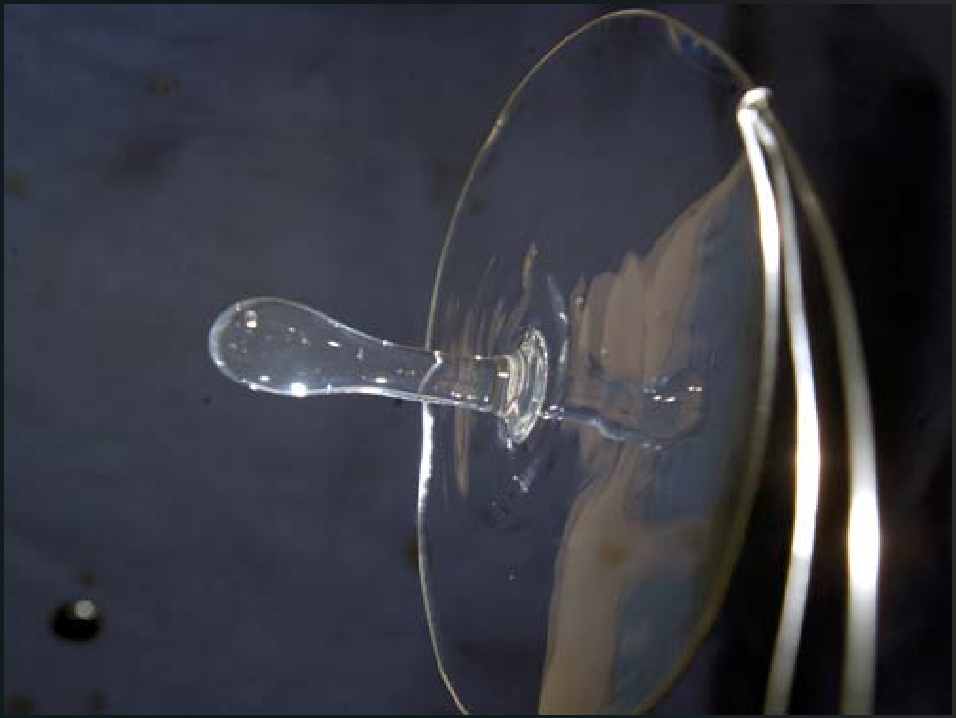
Gravity-Density Gradients

- On the ground, fluid systems stratify by density
  - Example: In a boiler, gases rise and separate from the liquids
- On orbit, there is no restoring force when the interface between phases is disturbed
  - Separation between gases and liquids is indeterminate
  - Good for particulate or droplet dispersal, bad for a boiler (or a cryogenic tank)

Gravity-Density Effects

- Buoyancy becomes insignificant
- Underlying processes on Earth emerge
  - Pressure-driven flows
  - Capillary flows
  - Diffusion
  - Viscosity
  - Electromagnetic forces
  - Vibration

Interfacial Phenomena



Capillary Effects

- Surface tension-induced rise/fall of a liquid in a tube
    - Static equilibrium shapes in microgravity well-examined
    - Uncontrolled excursions due to dynamic effects less quantified

- Can dominate flow in microgravity

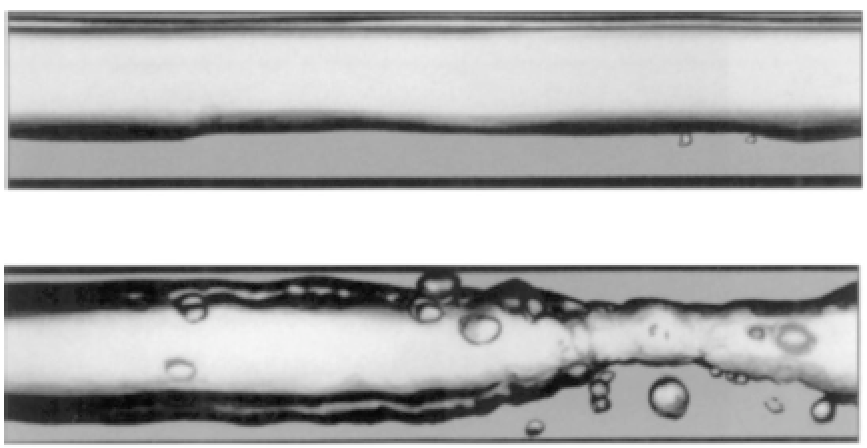
Wetting

- One condensed phase spreads over the surface of a second condensed phase
- Not significantly affected by presence of gravity
- Can become dominant in microgravity, though

Marangoni Effect

- Liquid convection caused by surface tension gradients
  - At the free surface of a liquid or interface between two liquids
  - Arises in the presence of temperature or composition gradients along the surface
- The counterbalancing viscous force to the resultant force from the surface tension gradient
- Dominant cause of diffusion in microgravity

Multiphase Flow



[Stratified flow, 1 g_0]

[Annular flow, microgravity]

Phase Separation & Distribution

- The phases in a flowing multiphase mixture may separate non-uniformly under acceleration
  - Result of large differences in inertia for each phase

- Flow regime transition can occur from lateral phase distributions

Mixing

- Chaotic mixing may occur due to turbulence
- May be possible to create metallic alloys with fibrous or multilayer film microstructures
  - Gravity-induced phase separation prevents this on Earth
- Flow of mixtures of immiscible liquids in microgravity little understood

Multiphase Flow Instabilities

- Excursive Instabilities
  - A boiling system may undergo Ledinegg-type flow excursions if the irreversible pressure loss in the system is much less than the external pressure change
- Pressure-Drop Instabilities
  - Flow excursions can be converted into periodic oscillations
- Density-Wave Oscillations
  - Stability increases as gravity is reduced

Flow in Porous Media

- Capillary and viscous forces control the phase distribution in microgravity
- No fundamental studies have been performed in reduced gravity or microgravity
- Theory suggests low-frequency gravitational oscillations could significantly affect flow stability

Heat Transfer

Conduction & Radiation

- Heat conduction in solids and liquids not affected by gravity
- Heat conduction in gases indirectly reduced in low gravity because gas density reduces
- Thermal radiation heat transfer is not affected by gravity

Convection

- Gravity can greatly affect fluid motion in convection
  - Evaporation
  - Boiling
  - Condensation
  - Two-phase forced convection
  - Phase-change heat transfer

Convection

- Evaporation
  - Not well-understood, but likely to be driven by surface tension and viscous forces
- Boiling
  - Available results are contradictory and do not allow for accurate prediction
  - In one experiment, bubbles grew as a result of direct heating from the rod

Convection

- Two-Phase Forced Convection
  - Measured heat transfer coefficients are sometimes lower than predicted by normal-gravity correlations
  - No experimental data for bubbly flow, little data for slug or annular flow
- Phase-change heat transfer
  - Melting likely to be affected by thermocapillary forces, instead of buoyancy
  - Solidification heat transfer has not been studied in theory or experimentally

Solidification

Solidification

- Nucleation in a liquid as a result of latent heat loss
- The lack of buoyancy-induced convection is dominant factor in microgravity
  - Affects distribution of temperature and composition at liquid/solid interface
  - Affects distribution of foreign particles and gas bubbles

Chemical Transformation

Ground On-orbit

Combustion

- The ratio of buoyancy to viscous forces, the Grashof number, is high on the ground
  - High temperature changes lead to large density changes
- “Quiescent” combustion studies are virtually impossible to conduct without some element of freefall
- Slow-flow combustion also difficult to study on the ground
  - High forced-flow velocity required to overcome buoyancy effects

Combustion

- Mixture Flammability
  - Flammability limits driven by radiative losses and/or effects of chemical kinetics
- Flame Instabilities
  - Driven by heat and mass diffusion and hydrodynamic effects
- Gas Diffusion Flames
  - Fuel flow and flame speed mismatching
  - Laminar flames longer and wider, more sooty
  - Radiative losses increase

Combustion

- Droplet Combustion
  - Unsteady effects initially slowly increase burning rates & flame diameters
  - Soot shells may form
- Cloud Combustion
  - Uniform dispersion may allow combustion of clouds that would not burn on the ground due to settling
- Smoldering
  - Oxygen transport to and product removal from smoldering surfaces absent in microgravity

Combustion

- Flame Spread
  - Opposed with respect to oxidizer flow
  - Reduced propagation speed from radiative losses can lead to flame extinction

- Thin Fuels
  - Flammability may be greater because low-speed opposing flow can overcome higher oxygen limiting concentration

Combustion

- Thick Fuels
  - No steady state spread
  - Increased conduction needed to raise the temperature of the heated layer
  - Enhanced radiative losses and decreased oxygen transport lead to flame extinction

- Liquid Fuels
  - Surface tension gradients draw the fuel out
  - Shallow pools behave similarly as on the ground

Pyrolysis

- Very dependent on the reactants and products involved
- Involves elements of many of the aforementioned processes
- For example, oxygen production from lunar regolith would be affected by gas diffusion and heat transport issues

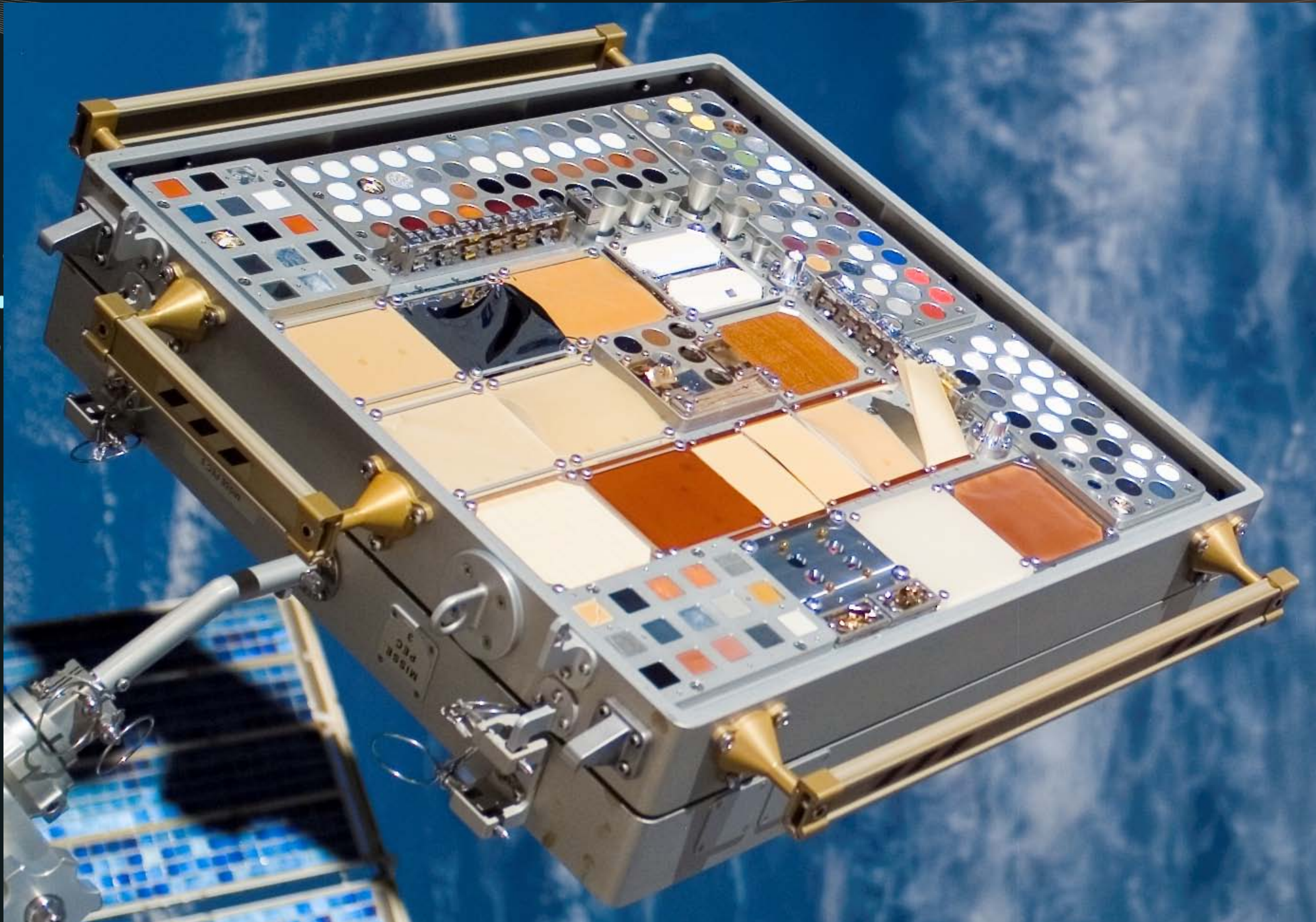
Solution Chemistry

- Density-driven convection cannot be used for mixing
  - Mechanical stirring and/or careful reaction chamber design can allow complete mixing
- Immiscible multiphase mixtures can remain suspended for longer
  - Enhanced phase interaction rates possible

Thermosphere & Observational Research

Thermosphere Exposure

- Rarified gasses stratify by molecular diffusion
- UV absorption keeps gas temperatures high
  - Even so, the energy lost by thermal radiation is greater than heat transfer from gas contact
- ISS resides in the F region of the ionosphere
  - Atomic oxygen is dominant constituent, flux of up to 4.4×10^{19} atoms/cm^3/day
  - Highest concentration of free electrons & ions: up to 10^6 e/cm^3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Fundamental Physics

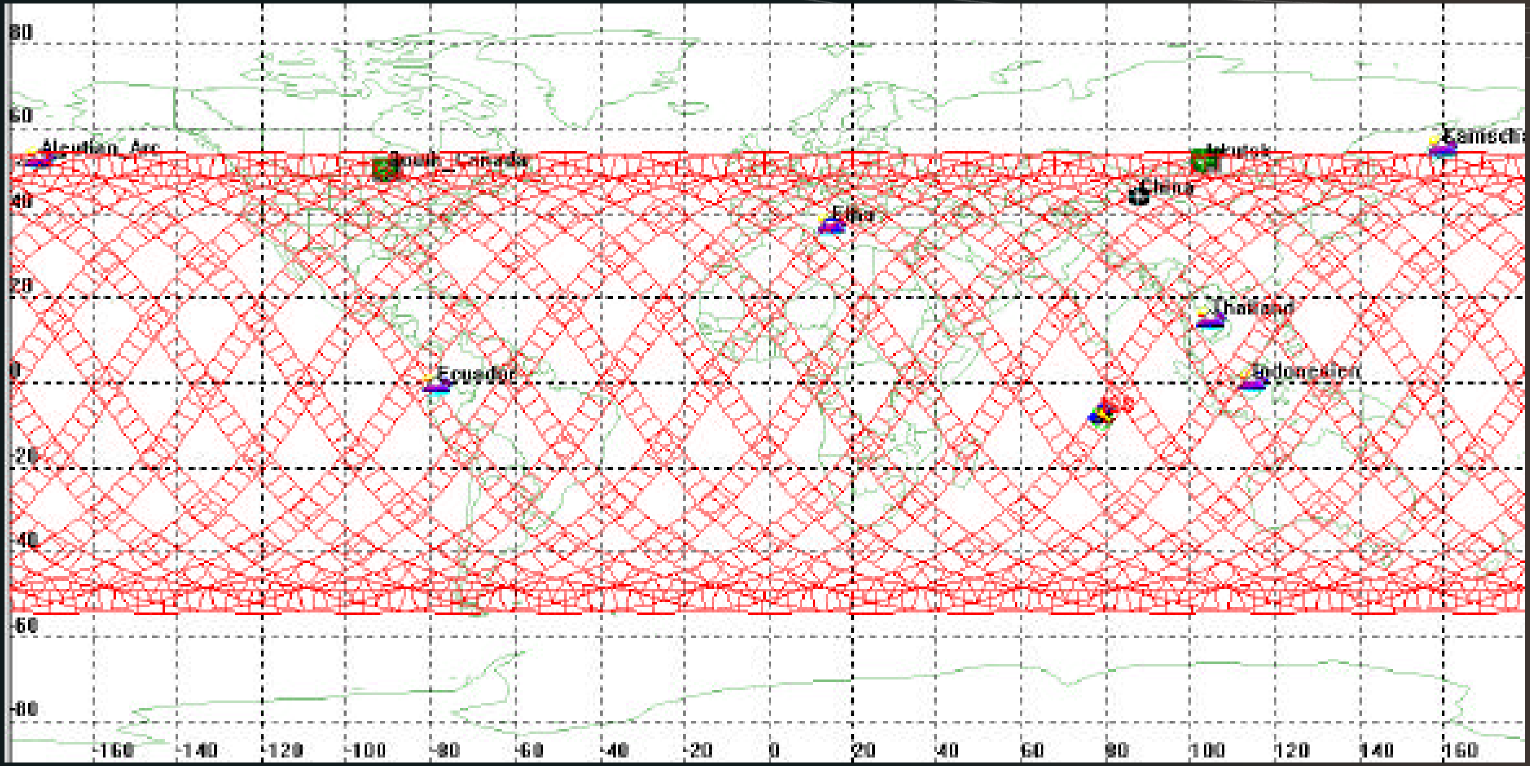
- **Critical points**
  - Samples are more uniform, thus easier to observe
- **Laser cooling**
  - Gravity no longer dominates atomic motion
  - More precise measurements possible
- **Direct testing of gravitation theories**
  - Atomic clocks

Earth Observation

- All geographical locations between 51.6° northern and southern latitude can be observed from ISS in nadir pointing
  - 95% of inhabited land area

- Using handheld motion compensation, station crewmembers have achieved a spatial resolution of less than 6 meters in photographs of Earth

Earth Observation



ISS coverage in 24 hrs for a 70°-swath optical payload. (Courtesy of ESA)

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